MEASUREMENT TECHNIQUES IN A 30-MM ELECTROTHERMAL-CHEMICAL (ETC) GUN FACILITY

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Abstract

Methods of acquiring data including pressures, load current and voltage, and "crow-bar" diode current and voltage with a minimum of electrical noise in electrothermal-chemical (ETC) ballistic and combustion experiments are described. Measurements are performed in a 30-mm ETC gun facility that is driven by a 130-kJ (maximum) pulsed-power supply and a 50-cm^3 closed chamber facility using a 300-kJ power supply, both of which are located at the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD. Strict attention is devoted to grounding measurement and data-recording devices, as well as to shielding measurement electronics, data lines, and high-power modulator components with "faraday" enclosures. The use of ferrite rings on data lines and 60-Hz power lines is frequent, and fiber-optical links are used for electrical isolation between data recording equipment and high-voltage components. The experimental arrangement and resulting data are presented, and comments and conclusions are included.

Background

The recording of experimental measurements in an ETC environment is complicated by the presence of a large noise-producing source, namely the pulse forming network (PFN). The block diagram (Figure 1) can be used to compare fundamental differences in measurements made in an ETC environment vs. those made in a conventional ballistic diagnostic facility. The most notable difference between the two arrangements is that of a high energy PFN in an ETC gun facility. While the PFN is an essential source of electrical energy needed to initiate the interior combustion process of an ETC gun, it is also, unfortunately, the source of large amounts of electromagnetic radiation that can interfere with small signal experimental measurements. As a result of this, much time had been devoted to the arrangement of the data acquisition systems of the U.S. Army Research Laboratory (ARL) ETC facilities, responsible for the measurement of experimental quantities. The following will provide a description of some of the measurement techniques that are used to help obtain reliable, noise-free experimental data.

Procedure

The experimental arrangement employed in the 30-mm ETC gun facility, shown in Figure 2, consists of various data acquisition equipment, a grounding system, the electrical power supply (including the high-voltage DC power supply and the PFN), an ETC diagnostic fixture, and a system of amplifiers and optoelectronics in support of pressure measurements. Nicolet digital oscilloscopes are used for recording experimental pressure, voltage, and current measurements with the feature of digital data storage on 5.25-in floppy disks. As indicated in Figure 2, two separate locations are used for grounding the oscilloscopes, and to date the resulting measurements in each case have provided very reliable experimental data, in terms of immunity to electromagnetic interference (EMI) (see experimental pressure measurement, Figure 3). The ground system that is used in this particular facility is made up of three separate earth-ground paths, each of which is in a different location. The first path (labeled No. 1 in Figure 2) occurs at the connection of the DC power supply to the electrical utility system. This is called the "service ground," and it is directly connected to the utility grounding network. A second ground path, the system ground, is made at the location of the diagnostic fixture. This path is made between the fixture and a fixture support ("I" beam) that is bolted deep into the floor of the Laboratory gun room. The third and final grounding location is in the control room, and it is used as a ground for the pressure measurements (see Figure 2). Kistler 607C piezoelectric pressure transducers are used for sensing chamber and gun tube pressure, and Kistler model 5004 amplifiers convert the output to a voltage signal that can be recorded with digital oscilloscopes. Low-noise coaxial cables carry the pressure signal from transducers to amplifiers and optical transmitters. The low-noise cables are shielded with copper braid that is firmly attached to the diagnostics fixture and serves as a ground path for undesirable noise current [1].

Frequency modulated optical links (Dymec model numbers 6723/6722) are used to provide electrical insulation and are incorporated into each pressure measurement channel. The optical links have an analog bandwidth of DC to 1 MHz, which is more than adequate for the signals that are measured in this application (~50 kHz), and rely on the frequency modulation of a 9-MHz carrier signal for data transmission. Because of the frequency modulation technique, the links are inherently less sensitive to attenuation and losses due to optical connectors or other perturbation in the optical fiber. Operational issues that are relevant to this particular application of these optical fiber links have been addressed by Fortier et al., at the ARL [2]. As indicated in Figure 2, the optical transmitters and the charge amplifiers are located in the interior of a "faraday" or shielding box, which is used to protect the equipment from electric fields. Each individual piece of equipment inside the faraday box is physically separated with nonconductive material from the other equipment and the structure of the box itself. Also, each piece of equipment has its electrical power (110 V, 60 Hz) supplied by a single 750-VA uninterruptable power supply (UPS). The reason for the three elements of EMI shielding, single-point grounding, and using a UPS is to prohibit the generation of electromagnetically induced noise and to prevent ground loops or paths which aid in the flow of noise current through grounded wires of data signal paths.

This methodology, in part, has been experimentally tested at ARL in the 130-kJ/30-mm ETC Diagnostics Laboratory. Figure 4 is a schematic diagram showing a view of the laboratory from above and the proximity of the various element of this experimental setup.

The purpose of the test was to determine what grounding and power-source configurations for this particular data acquisition arrangement were most successful in terms of acquiring noise-free electrical data. Since, under normal operating circumstances, it is required to make measurements in the harsh EMI environment of a discharging power supply, this experiment consisted of making measurements during the discharge of the 130-kJ PFN into a fixed 35-mohm resistive load. The PFN was discharged three times with a different data acquisition arrangement each time. During the discharges, measurements were made of di(load)/dt via a Rogowski coil (current sensing device) on the PFN output. The output from the coil was coupled, in parallel, to two separate digital oscilloscopes for each of the three discharges. One measurement is made directly with a 4094 Nicolet digital oscilloscope while another is optically coupled via a frequency modulated, Dymec fiber-optical link as previously described. A 100-m length of fiber-optic cable is used to connect the optical transmitter with the receiver. The initial stored energy level prior to the discharge is kept constant for all three discharges; in this case it is 10 kJ.

The setup of equipment in shot No. 1 (Figure 4) is as follows. The optical transmitter is placed physically close to the PFN (approximately 2 ft away from output connection), and it is powered by a 120-VAC receptacle outlet. The transmitter is also powered by a receptacle outlet; however, the grounding prong on the receiver unit is intentionally disconnected with the use of an adapter plug. The receiver output is terminated at the input of the second 4094 Nicolet oscilloscope, which also has an adapter plug disconnecting the grounding wire. The resulting measurements of load di/dt (Figure 5a) as recorded directly with an oscilloscope are quite clean and free from noise; consequently, the integrated waveform produced a noise-free load current trace. On the other hand, the measurement obtained with the fiber-optic link (Figure 5b) is so badly distorted that it does not in the least resemble the true waveform.

For the second discharge, the fiber-optic transmitter was powered by UPS. The UPS was disconnected from the utility power system (see

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14. ABSTRACT
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Figure 6); therefore, it is supplying the transmitter from a converted DC battery supply, which is completely electrically isolated from the utility network. The location of the UPS is in the interior of an ungrounded, metal "faraday" enclosure that is located 5 ft away from the nearest current carrying component (prepulse bank ignitron) of the PFN. The UPS is electrically isolated from all parts of the metal enclosure, and a household-grade extension cord, running parallel to the PFN, is used to connect the UPS to the optical transmitter. This arrangement of the transmitter and UPS is such that all equipment on the measurement or transmitting side is ungrounded or left "floating" from the PFN and utility grounds. The AC cord of the UPS is external to the faraday enclosure, and the fiber-optic receiver and oscilloscope are set up identically as in the first shot. In this case, the resulting measurements (Figure 7) from both arrangement are completely free of noise; in fact, they are nearly identical when compared directly.

In the third and final discharge, the experiment was unchanged with the exception of the removal of the UPS from the enclosure to a location very close to the PFN (2 ft from load/output connection) (as in Figure 8). The results from this test (Figure 9) are along the lines of the second test, thus indicating that under similar circumstances a UPS should be used rather than utility power as a means of acquiring noise-free data. This may be true, however, only when using this particular arrangement of data acquisition and optoelectronic equipment.

It should be mentioned, a transient noise problem associated with the UPS was observed during similar tests, and it appears as though large noise "spikes" or peaks in line voltage were introduced into the pressure channels (see Figure 10) by the UPS itself. Figure 10 shows the baseline of a pressure transducer mounted on an ETC fixture. Figure 10a shows the baseline in a 4-ms window while Figure 10b is of a 30-ms window. The arrangement for this pressure channel is as shown in Figure 2. The UPS is in the battery-powered mode, and it is supplying inverted AC power to the charge amplifier and the optical transmitter. It is noticed that with only the UPS operating (battery mode), transient voltage "spikes" with magnitudes of about 100 mV are introduced into the pressure channel. The noise occurs at 800 μs in the trace of Figure 10a and in 16-ms periods in Figure 10b (note that a positive spike is missing at 16-ms periods in Figure 10b because the digital sampling of the oscilloscope was not fast enough to capture all the transients in this window). It is very clear by examining Figure 10b that this transient noise is a result of the 60-cycle (16-ms period) UPS power source. This is true since the transient noise occurs in 16-ms periods or when the UPS inverter completes a positive and negative cycle. Thus, positive as well as negative transients should be expected every 60 cycles or every 16 ms, and this is evident in the 30-ms trace of Figure 10b. One solution to this problem was in the design of a third-order, low-pass filter with a cutoff frequency of 7.5 kHz. A lowpass filter of this type will allow 60 Hz to pass unattenuated, but it will rid the power supply of noise above the 7.5-kHz cutoff (note the transient noise is above the 7.5-kHz cutoff). The gain-vs.-frequency plot for the filter, and the filter itself, are shown in Figure 11, and by introducing this to the output of the UPS, the noise was eliminated from the 60-Hz UPS power supply and from the pressure channel baseline trace (Figure 12). Based on the results of this particular test, it is suggested not to overlook this problem if any electronics equipment in the data acquisition system is powered by a similar UPS.

A technique using rings of ferritemagnetic material is employed to attenuate the amplitude of noise currents that flow in the shield or grounded conductors of any electrical equipment in the data acquisition system. The technique has been described by others including Matthew et al. at the U.S. Naval Research Laboratory, Washington, DC, as a "common mode rejection device" because it is used to attenuate or reject signals traveling in the ground or common conductors of a circuit [3]. The ferritemagnetic rings or "ferrites" contain iron oxides, and they generally have a relatively high permeability. This characteristic enables the ferrite to introduce an amplification effect on the magnetic field (or inductance) generated by current-carrying conductors surrounding the material. Common ferrites include $NiFe_20_4$, $MnFe_20_4$, and $(Zn,Mn)Fe_20_4$ [4]. The power cords and coaxial data lines of all electronics equipment are wound tightly for several turns around the ferrites as shown in Figure 13. Figure 13 shows the circuit diagrams of the resulting arrangement with the addition of a ferrite. The circuit includes a voltage source (or data signal), the series resistance of the data lines (Rs), the inductances due to the windings around the ferrite, and the load voltage measurement. By examining the circuit closely, it can be seen that for the current from the data signal, the ferrite inductances are self canceling. This is due to the fact that data current flows bidirectionally around the ferrite, thus generating opposing magnetic field (inductance) through the ferrite. The addition of the inductance generated in this path will, like the addition of impedance to any circuit path, have a tendency to decrease the current amplitude. Although this is a desirable situation if a ground loop is introduced into the measurement system, its effectiveness is limited by the frequency of the noise current. This is because, as illustrated in Equation 1, the impedance introduced by the ferrite (XL) is proportional to the product of frequency and inductance.

$$XL = wL = 2*\pi*f*L. \tag{1}$$

In Equation 1, f is the frequency of the applied signal (in hertz), L is the inductance (in henrys), and π is a constant (3.141). As an example, the impedance offered by a typical inductance at 100 kHz can be as much as 1,256 ohms, which will have a pronounced effect on current traveling in a ground loop having an impedance of fractions of an ohm (Rs = 0.1 ohm typ.). However, the same inductance will produce only 12.56 ohms of impedance for the same current at 1 kHz. Even so, the attenuation effect of a common-mode rejector on lower frequency signals can be seen experimentally as in the data of Figure 15. Figure 15 shows the result of noise coupled into a pressure channel (in the absence of pressure) during a PFN discharge into a nearby resistive load. The only difference between the two arrangements is that in Figure 15b, the pressure channel circuit contains a 20-turn ferrite whereas the circuit of Figure 15a has no ferrite.

Conclusions

In summary, the design of a data acquisition system that allows for reliable, noise-free experimental measurements in the ETC gun environment at ARL, has been described. This includes a system of shielded pressure channels, optoelectronic equipment, an uninterruptable power supply, digital oscilloscopes, and a multipoint grounding system. Tests have been performed to determine a sound arrangement for grounding and power supply for a particular type of optoelectronic and amplifier equipment. Also, a filter design has been offered for the elimination of voltage "spikes" that are introduced by the switching elements of an uninterruptable power supply. Finally, a technique involving common mode rejectors (ferrites) used to attenuate ground loop currents has been described, and experimental data showing its effectiveness were put forward.

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[4] D. R. Askeland. The Science and Engineering of Materials. Prindle, Weber, and Schmidt, 1985.

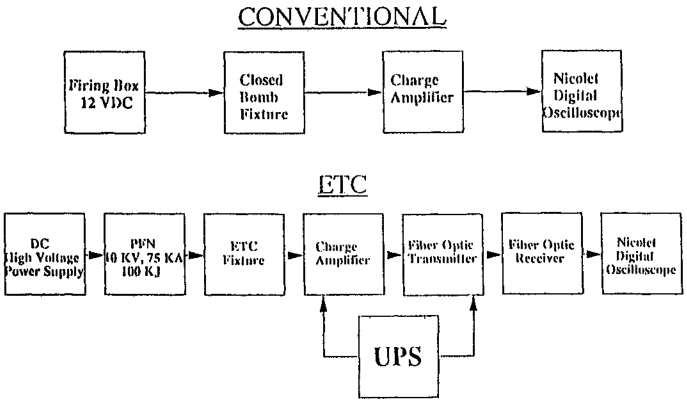


Figure 1. Comparison of ETC to Conventional Data Acquisition Systems.

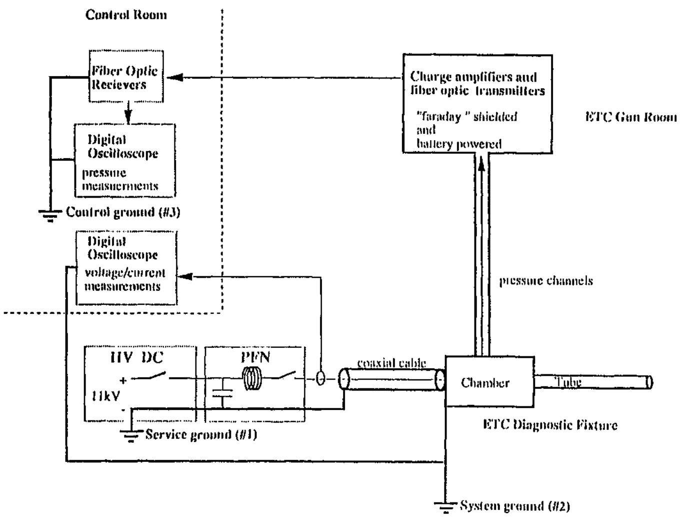


Figure 2. ETC Gun Diagnostics Arrangement.

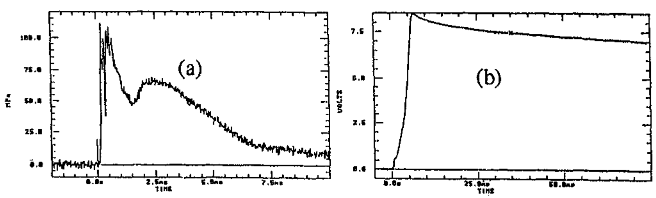


Figure 3. Pressure Measurements With Oscilloscope Grounded at the (a) System Ground and (b) Control Room Ground.

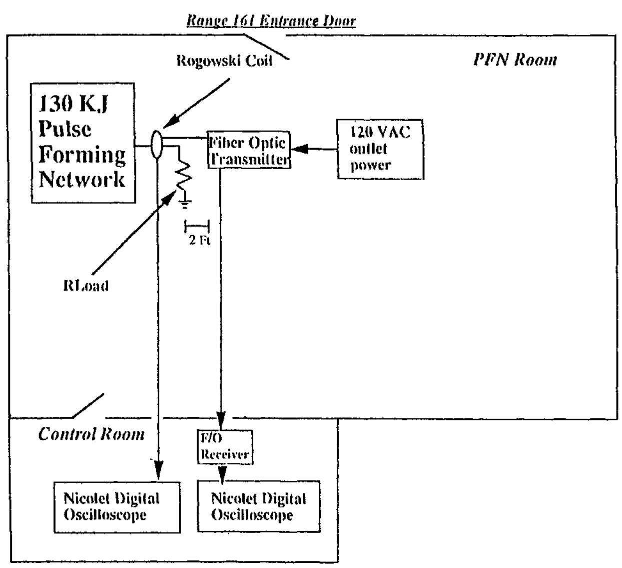


Figure 4. Experimental Setup for Test No. 1.

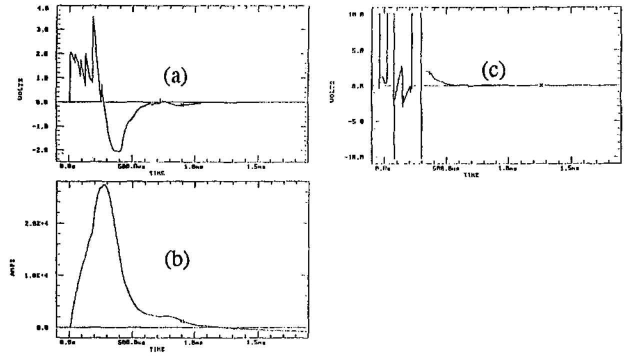


Figure 5. Load di/dt Waveform for Test No. 1: (a) Direct di/dt Measurement, (b) Numerical Integration of (a), and (c) Optically Coupled Measurement.

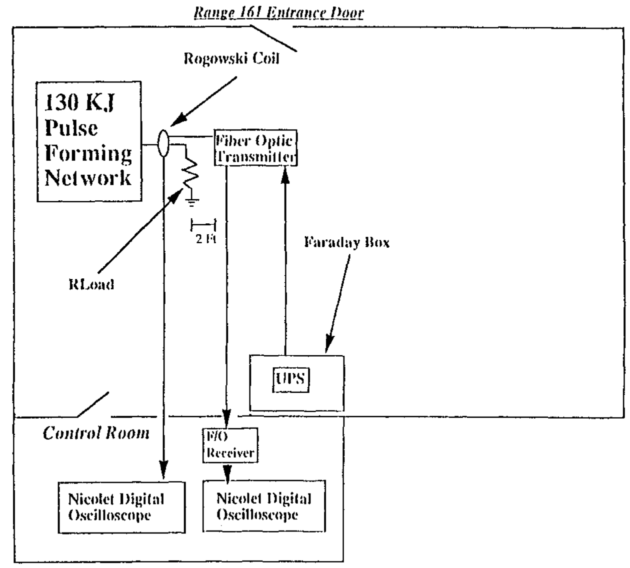


Figure 6. Experimental Setup for Test No. 2.

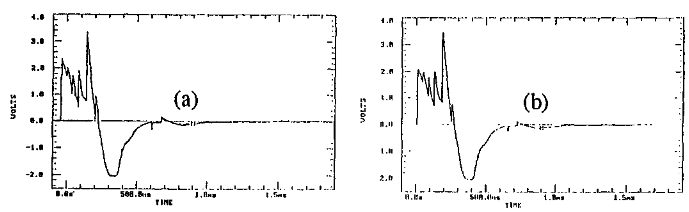


Figure 7. Load di/dt Waveform for Test No. 2: (a) Direct Measurement, (b) Optical Coupling.

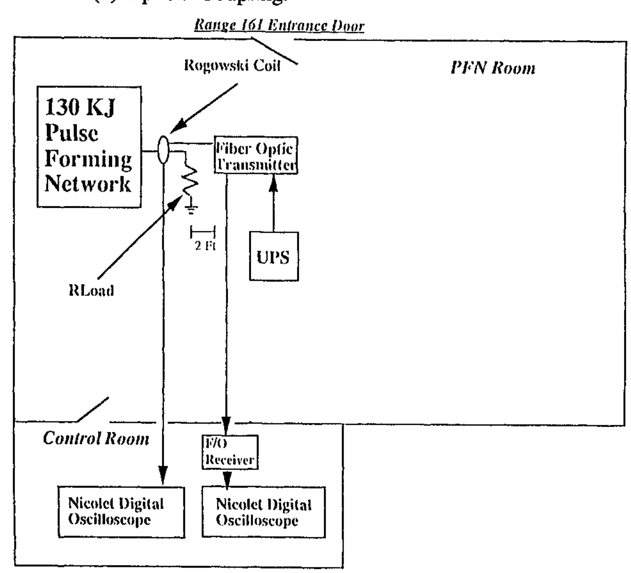


Figure 8. Experimental Setup for Test No. 3.

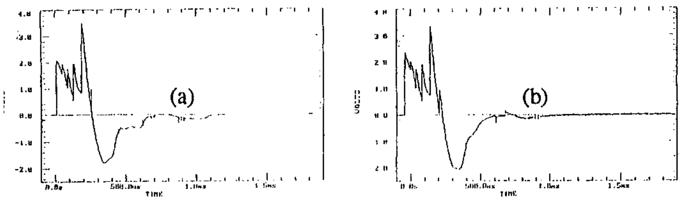


Figure 9. Load di/dt Waveform for Test No. 3: (a) Direct Measurement, (b) Optical Coupling.

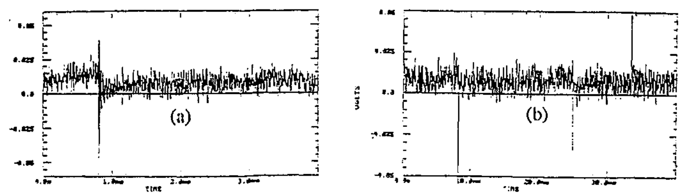
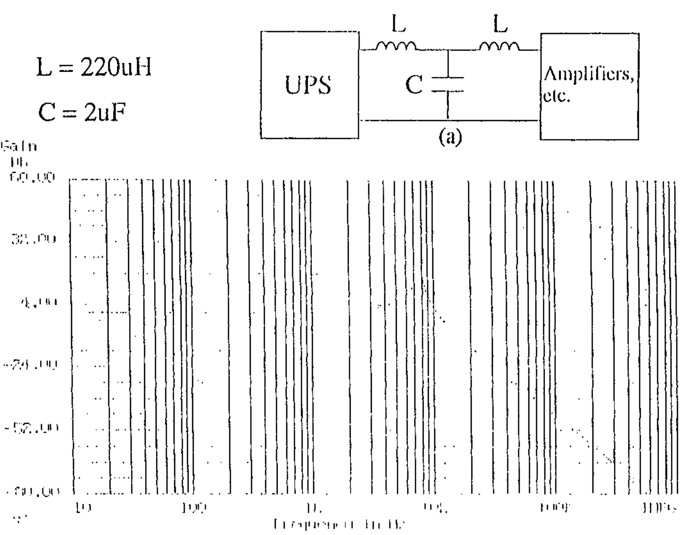


Figure 10. Pressure Channel Baseline With Transient Noise: (a) 4-ms Window, (b) 40-ms Window.



(b)

Figure 11. (a) Circuit Diagram for Third-Order Low-Pass Filter; (b) Magnitude-vs.-Frequency Plot for Filter.

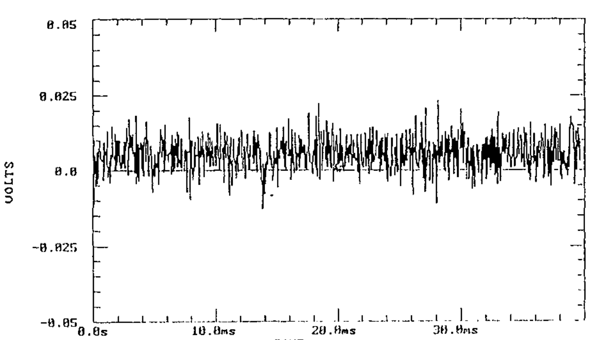


Figure 12. Pressure Channel Baseline With Addition of Filter.

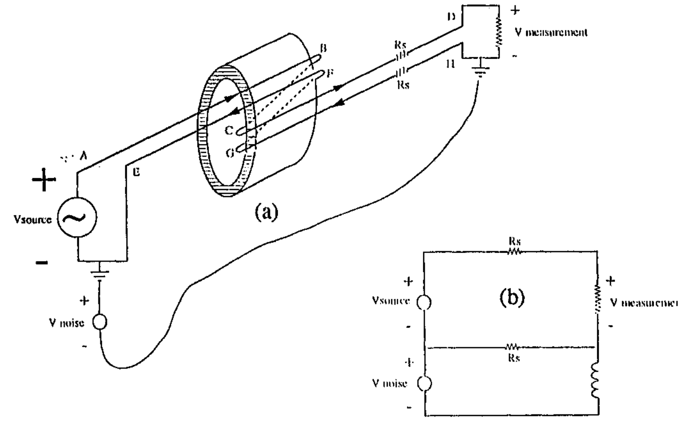


Figure 13. (a) Schematic Diagram for Common Mode Rejector; (b) Equivalent Circuits for Common Mode Rejector.

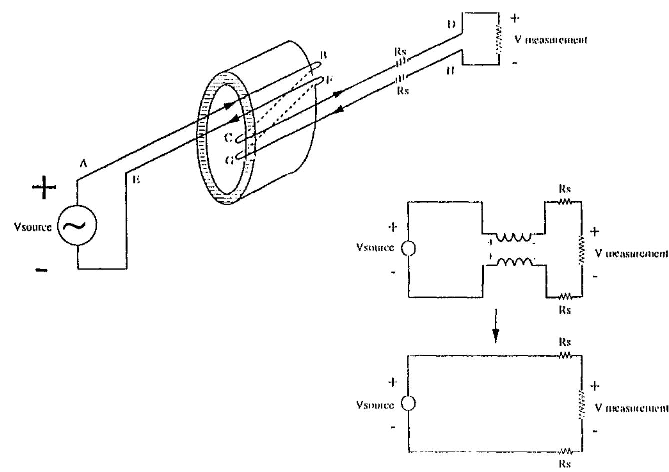


Figure 14. Common Mode Rejecter With Circuit Having a Ground Loop.

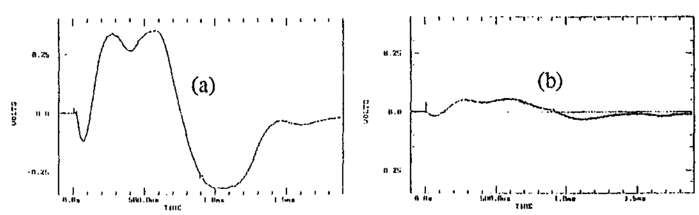


Figure 15. Noisy Pressure Channel (a) Without Rejecter, (b) With 20-Turn Rejecter.